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Forage Fish: From Ecosystems to Markets

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Key Words

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Abstract

Fisheries targeting small-to-medium pelagic, so-called forage fish, impact on human food security and marine ecosystems. Because their operations are shrouded by the myth that forage fish are unsuitable for human consumption, the role of these fisheries in intensive food production is not well understood or appreciated. Thus, although they account for over 30% of global landings of marine fish annually, our knowledge of how these levels of removal impact on marine ecosystems is limited. Nevertheless, there is considerable scope for policy makers to change the current management of these fisheries and to enhance their contribution to food security and economic development. Industry and consumers also have an important role in finding the balance between these fisheries contributing to human food security and poverty alleviation on the one hand, and sustaining intensive animal food production systems, especially aquaculture, on the other.

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INTRODUCTION

Forage fish are often described as the prey for other animals to eat and are composed primarily of small- and some medium-sized pelagic fish. Forage fish are used directly for human food and reduced to fishmeal and fish oil for industrial purposes. The current state of fisheries, the growth in the aquaculture sector, and impending changes from increasing sea temperature raises the question of the future of these fisheries because they are a source of food for many of the world's poor as well as a critical input to the current expansion of aquaculture especially for high-value carnivorous species. This review attempts to examine the interaction of forage fisheries, ecosystems, and intensive food production.

Forage fishes tend to form large dense schools, which make them easy to catch using little fuel energy, especially in comparison with demersal fish, typically caught by bottom trawling. Forage fishes (e.g., anchovies,[1] sardines, and mackerels) school and are easy to catch in large numbers, and hence inexpensive. The fisheries that rely on forage fish are found throughout the world's oceans, except in Antarctica (1). Presently the annual catch is about 31.5 million tonnes, a staggering 37% of global marine landings (2). However, the largest catches occur in three areas of the world, the west coast of South America (southeast Pacific), which sustains the world's largest (by volume) fisheries; northern Europe; and the United States (the East Coast and Alaska). These fisheries are not only important to human well-being, but also as food for marine mammals and seabirds (1).

Small pelagics play a crucial role in most ecosystems because they are the group that transfers energy from the plankton to the larger fishes and marine mammals. Along with their short life span, the direct dependence of these fishes on plankton, which are impacted by environmental fluctuations, often causes the biomass of these fishes to fluctuate more strongly than other commercial fish species (3). This has led many fisheries scientists to conclude that fisheries have little impact on small pelagics, as their abundance seems determined mainly by environmental factors. Yet, intense fishing pressure on small pelagics does result in, among other things, depleting the food base of seabirds (4) and marine mammals (5).

Historically, humans in all areas of the world consumed small pelagics, and in many countries, these fish contribute significantly to human diets, particularly among people with low incomes. However, their low prices, owing in part to their schooling behavior, which implies low fuel and other fishing costs, and their high nutritional value, also make them an important input of animal feeds for poultry and pigs, and more recently for farmed fish. The economics of fisheries for small pelagics are thus impacted by factors, such as the price of soymeal and other inputs to animal feeds, which are well beyond the control of fishers and fishmeal producers.

The growing practice of fish farming, especially of high-value, carnivorous fish, requires

[1] In this article, we use common names, standardized by the American Fisheries Society; for the corresponding scientific names, see **http://www.fishbase.org**.

increasing amounts of fishmeal and fish oil. This demand is met, in part, by increasing the fraction of fishmeal diverted away from animal husbandry, by increasing the pressure on small pelagics (including previously unexploited species), and by improving the efficiency of the use of fishmeal and fish oil (6).

The extraordinary responsiveness of small pelagic fishes to environmental fluctuations, and their apparent resilience to fishing, has been the focus of much research, which has yielded powerful generalizations (7). However, ensuring sustainable catch levels in the face of environmental variability and growing industry demand has remained a challenge. In addition, their potential role in contributing to human food security, in sustaining and potentially constraining the aquaculture sector, and their ability to transport persistent organic pollutants through the international trade in aquafeed are hardly explored, as argued below.

LANDINGS OF FORAGE FISH SINCE 1950

Although small pelagic fishes have been exploited for millennia, it was not until the 1950s that these fisheries became industrialized. Today, small pelagic fish make up 37% of the total capture fish landings, and 90% of these landings (or 27% of total landings) are processed into fishmeal and fish oil with the remaining 10% of these landings used directly for feed for animals (2).

Although herring, sardines, and menhaden were the main species targeted for reduction (i.e., processed/reduced into fishmeal and fish oil) early in the twentieth century, the range of species targeted has expanded (**Table 1**). Landings destined for reduction also increased very slowly until 1958, when large industrial-scale fishing for Peruvian anchovy began (**Figure 1**). This fishery is the world's largest with landings of 10.7 million tonnes in 2004, virtually all of it already destined for reduction (2). Landings of fish are highly variable as seen in total global landings of these fish in the three major fishing areas (**Figure 1**).

Table 1 Species that made up 75% of the fishmeal produced globally in 1950, 1976, and 2001[a,b]

1950	1976	2001
Atlantic herring	Peruvian anchoveta	Peruvian anchoveta
Atlantic menhaden*	Capelin	Inca scad*
Japanese pilchard*	South American pilchard	Capelin
Gulf menhaden	Chub mackerel	Blue whiting
Chub mackerel	Atlantic herring	Japanese anchovy*
European sprat	European pilchard*	Chub mackerel
Capelin	European sprat	South American pilchard
Blue whiting	Norway pout*	Atlantic herring
Pacific menhaden*	Atlantic mackerel	Threadfin breams*
Peruvian anchoveta	Gulf menhaden	Sand lances
Chilean jack mackerel	Sand lances	Gulf menhaden

[a]An asterisk shows species present in only that year.
[b]Data from 1950 are based on Grainger & Garcia (48); other data are from the Sea Around Us database (49).

The expansion of the industry surrounding reduction fisheries from the late 1950s saw a dramatic global change in the species composition of fishmeal (**Table 1** and **Figure 2**). In 1950, Peruvian anchovy made up a very small proportion of the global production of fishmeal. However, by the late 1960s, it was the major species used for fishmeal (**Figure 2*a***), and in 2003, Peruvian anchovy contributed 57% of global landings used for fishmeal production (8). Other important species used for fishmeal are South Pacific hake and Inca scad, caught mainly off Chile.

In northern Europe, a major forage fish is capelin, which makes up to 10% of fish landings globally used for fishmeal; other species include European sprat, Norway pout, and haddock (9). European sprat declined, beginning in the 1960s, as a major component of fishmeal; Norway pout followed a similar pattern, with landings peaking in the mid-1970s and then declining steadily, with current catches of less than 100,000 tonnes.

Initially, blue whiting was caught as bycatch, but as other fish species traditionally used for fishmeal were depleted, a targeted fishery developed in the late 1960s (9). Thus, blue whiting, in 2007, contributed over 73% of fish destined for reduction in Norway (10).

Capture fish landings: fish caught using a variety of gear, such as nets and hooks; not farmed fish

Reduction fisheries: generally small pelagic species that are processed into fishmeal and fish oil

In the United States, Atlantic and Gulf menhaden have been used, since the early 1900s, for producing fishmeal and fish oil, and this use continues amid controversy, especially because Atlantic menhaden is food for recreational species of fish. Japan has an even longer history of fishmeal production, using Pacific saury, Pacific herring, and sardines. In southwest Africa, landings of fish used for reduction have declined since peaking in the 1960s, with catches annually fluctuating around 850,000 tonnes.

In recent years, the use of Antarctic krill for fishmeal and fish oil has increased. In the 2005–2006 fishing season, landings totaled 106,000 tonnes; in spite of predicted increases, catches remain well below the catch limit of 6.5 million tonnes (11).

Many forage fish are highly sensitive to oceanographic changes and landings are highly variable from year to year. For example, in strong El Niño years, the abundance of Peruvian anchovy declines, and that of South American pilchard increases (12), which is reflected in the catch, and ultimately in the composition of the fishmeal. This variability affects the quality of the product as anchovy meal is preferred. Globally, there is a tendency, since the mid-1980s, toward increasing the proportion of carnivorous fish used for fishmeal, as indicated by the increased trend in mean trophic levels in **Figure 3**, which shows only Africa as a region where this trend did not occur until the mid-1990s.

These high fluctuations in the abundance of small pelagic fishes also led to questions regarding sustainability. For fisheries where assessments are available, each one's status has been assessed as sustainable by various organizations (8, 13). However, not all stocks are within safe limits (**Table 2**). North Sea herring, for example, were used for reduction until 1997, when the stock collapsed and the European Union (EU) banned its use for reduction (14).

Most fisheries are under some form of management, and given their sensitivity to changing oceanographic conditions, a precautionary approach to management, including setting of quotas and effort limits, is needed within an ecosystem-based management approach (15). Blue whiting is noteworthy because it is one of the major inputs of fishmeal and fish oil in Europe. The stocks in the North Atlantic are exploited by a number of countries within and outside of the EU, which, until 2006, could not agree on quotas for the fishery. In 2006, landings totaled over 1.97 million tonnes, close to the recommended quota of 1.9 million tonnes by the International Council for the Exploration of the Sea (ICES) (16).

The upward trend in the average trophic level of landings destined for reduction (**Figure 3**) contrasts with the downward trend in the average trophic level of fish for human consumption, i.e., "fishing down the food web" (17). This indicates that an increasing amount of fish suitable for human consumption is being diverted to make fishmeal. The demand for fishmeal and fish oil is driven by intensive animal production systems, seeking inexpensive, yet valuable, components to animal feeds. This increasing demand has expanded the number of species of fish targeted for reduction, which now has grown to include higher trophic level species; this expansion increasingly results in competition with human needs.

FORAGE FISH IN A MARINE ECOSYSTEM CONTEXT

Forage fish play a crucial role in marine ecosystems, mainly because they are the group that transfers energy from the plankton to the larger fishes and marine mammals. Hereby, they operate at the crucial "wasp-waist" trophic level, where one or more small plankton-consuming nektonic species tend to dominate the trophic transfers, as opposed to the many species involved in transfers at lower and higher trophic levels (3, 12).

Still, a study of the impact of reduction fisheries on EU marine ecosystems concluded that "the impact of industrial fisheries we were able to identify is relatively limited compared to the effects of fisheries for species destined for human consumption" (18). The researchers concluded that the overall impact of industrial

Table 2 Stock status for fish destined for reduction in 2002 (56)

Target stock	FAO area[a]	State of exploitation in 2002[b]
Atlantic menhaden	NW Atlantic FAO21	F
	WC Atlantic FAO31	F
Gulf menhaden	WC Atlantic FAO31	F
Atlantic mackerel	NE Atlantic FAO27	F
Blue whiting	NE Atlantic FAO27	O
Norway pout	NE Atlantic FAO27	F
Sand eels/sand lances	NE Atlantic FAO27	F
Atlantic herring	NW Atlantic FAO21	U, F, R
	NE Atlantic FAO27	F
European sprat	NE Atlantic FAO27	F
	Mediterranean and Black Sea FAO37	D
Capelin	NE Atlantic FAO27	F
Chub mackerel	EC Atlantic FAO34	F
South African anchovy	SE Atlantic FAO47	F
Horse mackerel	SE Atlantic FAO47	M, F
Pilchard	SE Atlantic FAO47	F
Pacific herring	NW Pacific FAO61	?
Pacific saury	NW Pacific FAO61	F
Japanese sardine (anchovy)	NW Pacific FAO61	F
Peruvian anchoveta	SE Pacific FAO87	R, O
South American pilchard	SE Pacific FAO87	F, O
Chilean jack mackerel	SE Pacific FAO87	F, O
Hake	SE Pacific FAO87	F, O, D

[a]Multiple values of exploitation are due to multiple stocks within the UN Food and Agriculture Organization (FAO) area being in different states of exploitation.
[b]D, deleted; F, fully exploited; O, overexploited; U, underexploited; R, recovering; M, moderately exploited; ?, unknown.

fisheries is relatively limited on predators, but interactions with certain populations of predators can be locally significant. Most incidental catches are also species used for fishmeal, and where edible species are caught incidentally, they generally represent a low proportion of the catch, which is considered acceptable by the EU (14). However, concern in the United Kingdom over the role of sand eels as food of seabirds resulted in the EU banning catches of sand eel in an area of 20,000 km^2 in the North Sea (14).

Strong interactions are also documented in South America, especially in El Niño years, where significant mortalities of seabirds and marine mammals occur, owing in large part to a reduction in prey abundance (4). Changes in the Benguela upwelling system also result in substantial mortalities of seabirds and marine mammals (19). In the United States as well, there is growing concern over the landings of menhaden impacting the catch of striped bass in the Chesapeake Bay (20).

Our understanding of the forage fish role in supporting seabirds and marine mammals is still limited. However, recent research (21, 22) provides considerable insight into the consumption of these fish by seabirds and marine mammals, as presented below.

CONSUMPTION OF FORAGE FISH BY SEABIRDS

A database of 351 species of seabirds was combined with a seabird food consumption model to estimate the global consumption of small pelagic fishes by all seabird species combined

(21). This led to the result that this consumption was, in the 1990s, at least eight times lower than the fisheries catches of these same fishes today (22). Small pelagics are about 12.5% of the overall food consumed annually by the world's seabirds. Alcids (puffins and murres) and larids (gulls) are responsible for about 75% of small pelagic fish consumption by all seabird species combined.

The work predicted that more than 52% of the forage fish that seabirds consume is extracted over the continental shelves of the northeast Atlantic Ocean (**Figure 4**). In this area, sand lance and capelin accounted for >54% of the food taken annually by seabirds. The eastern Central Pacific Ocean (**Figure 4**) was the second most important area, where small pelagics taken by seabirds are 21% of the overall forage fish consumption. In this area, forage fish groups in seabirds' diets were dominated (up to 92%) by fish species of the family Exocoetidae. Areas of highest forage fish consumption were closely linked with the distribution of those seabird species that are limited to waters above continental shelves when foraging (23).

Furthermore, predicted maximum food consumption rates exceeded 10 $t \cdot km^{-2} \cdot year^{-1}$ along the continental shelves of the northeast Atlantic Ocean and around islands of the western Central Pacific Ocean. However, seabird consumption still remains several orders of magnitude lower than the highest fisheries catch rates.

Direct competition between fishing operations and seabirds is not a significant threat to species with large foraging ranges on the basis of the small size of predicted hot spots. In contrast, our findings support a previously proposed hypothesis that the most common type of harmful competitive interaction will be one in which fisheries adversely impact species with restricted distributional ranges (24, 25) (indicating that local depletions of food resources through intensive fishing, as for example, in the North Sea populations of Black-legged kittiwakes) and also localized populations of other species.

Resource overlap does not automatically imply competition and vice versa; however, it is reassuring that the hot spots of potential conflict, highlighted by their approach, coincide with many areas that have been the focal points of much previous debate about seabird-fisheries interactions. Several areas of potential conflict for seabirds were identified, for instance in the Norwegian and Barents Seas, where rapid decline in the numbers of Common murres has been attributed to the development of industrial fisheries, which target mainly sand eel for industrial raw materials, fish oil, and fishmeal (26).

By contrast, there is a growing literature on seabirds being starved by depletion of small pelagics by fishing. For example, the development of an anchovy fishery offshore of Chubut, Argentina, has raised concerns over Magellanic penguins and other wildlife (27).

CONSUMPTION OF FORAGE FISH BY MARINE MAMMALS

Maps of the distribution of 115 species of marine mammals (22) were combined with population, diet composition, and food consumption estimates to obtain a model of the fish consumption of marine mammal (28), subsequently used to estimate forage fish consumption by all marine mammal species (22). The key result was that marine mammals consume about two thirds of the fisheries' catch of small pelagics in the 1990s. Although small pelagics represent the single most important prey type targeted by fisheries, contributing over 50% of the total catch, this food type makes up—at the most—20% of the diet of any marine mammal species group. Baleen whales and pinnipeds (seals, sea lions, and their relatives) consume the bulk of small pelagics consumed by marine mammals. Toothed whales, in contrast, are much less dependent on forage fish, and this prey type eats less than 10% of the total amount consumed by both small and large species.

The food consumption models predicted that much of the forage fish that marine mammals consume occur at high latitudes, with high

consumption rates on continental shelves in the North Atlantic (**Figure 5**). Owing to the sheer size of the distributional ranges of many of the baleen and larger toothed whales, consumption densities (annual food intake per km^2) are comparatively low and homogenous across large areas (**Figure 5**). Areas of highest forage fish consumption are closely linked with pinniped occurrence because of their coastal ranges and their frequently high local abundances. However, predicted maximum food consumption densities did not exceed 0.75 $t \cdot km^{-2} \cdot year^{-1}$ anywhere in the world, i.e., maximum food intake of small pelagic prey by marine mammals is several orders of magnitude lower than the highest fisheries catch rates.

Overall, a low overlap in resource exploitation between all marine mammals and fisheries was inferred (**Figure 6**). High overlaps appeared to be restricted to small geographical areas, mostly on high-latitude continental shelf areas of the Northern Hemisphere and on highly productive upwelling systems in the Southern Hemisphere. The highest overlap occurred in areas where high fishing effort coincided with high densities of seals, such as the North Atlantic shelves (containing harp, hooded, harbor, and gray seals), the Benguela upwelling ecosystem (containing South African fur seals), or along the coast of western South America, where upwellings support a wide range of marine mammals and fisheries. Although only a few pinniped species occur in the waters around Japan, high overlap in this region can be attributed to the large number of dolphins and some baleen whale species feeding on small pelagic fishes, combined with very high fishing rates.

FOOD SECURITY AND SAFETY

In many areas of the world, especially developing countries, forage fish are important for food security. Their importance contrasts with the notion that the reduction of such fishes to fishmeal and fish oil has no impact or only a positive impact on human food security. Almost all the small fish dominating reduction fisheries are (or were) eaten by people, for example:

- The Peruvian anchovy, was consumed in Peru until reduction fisheries were introduced in 1953, and there are new efforts to turn it into an upscale food (29);
- Some capelin is frozen for specific markets in Japan and Europe, and the market appears to be increasing (30) with predictions of increased share of landings going for human consumption (30a);
- Approximately 33% of Japanese pilchard landings are destined for human consumption;
- Chilean jack mackerel was historically used for human consumption as a frozen or canned product sold in Latin America, Africa, and Oceania, although it is now used mainly for fishmeal;
- Round sardinella are frozen and exported to Africa, Asia, and Eastern Europe for human consumption (31); and
- European anchovy is consumed as a fresh, dried, smoked, canned, or frozen product (31a).

Current regional patterns of small pelagic consumption suggest that the use of forage fish for animal (including fish) husbandry competes directly with human consumption in some areas of the world. Overall, there is a declining human consumption of relatively cheap pelagic fish, and in richer countries, an increased consumption of expensive seafood, some of it farmed with aquafeeds derived from small pelagics.

FORAGE FISH CONSUMED BY HUMANS

The small pelagic fish species that are eaten vary between geographic regions and reflect historical and current taste preferences. These fish, owing to their schooling habits, are easy to catch using small mesh nets with low operating costs and are relatively easy to preserve. Consequently, for low-income groups, the fish are often much cheaper and more accessible than demersal fish. Where the demand for animal

Figure 7

Forage fish landed and consumed directly by humans as a percentage of global landings (49, 50).

protein (or for cheap protein) is not met domestically, such as in West Africa, the Caribbean, Oceania, and Latin America, imports of small pelagics, such as herrings, sardines, and mackerel, are often used to meet that demand (31, 32).

The percentage of forage fish catch that is landed and consumed directly as food has fluctuated between 10% and 20% of global landings since 1961 (**Figure 7**). Much of the variation is a reflection of the environmentally induced variation in landings of small pelagic fish.

The trend in per capita consumption of forage fish varies with each continent (**Figure 8**) and represents between 10% and 25% of per capita consumption of fish globally. In Africa and Oceania, where these fish play an important role in food security, per capita consumption has declined since the mid-1980s in Oceania and late 1990s in Africa. Consumption has declined since the late 1970s in South America and since the late 1980s in North and Central America. In Asia, where these fish are also important for food security, per capita consumption has remained steady, and in Europe it has increased since the late 1980s (**Figure 8**).

A recent study (33) examined trends in "low-value food fish" and noted that low-value food fish as a proportion of total fish consumed by humans in developing countries dropped by 11% from 76% in 1973 to 65% in 1997. However, if China is excluded, the decline (5%) is much less, from 77% in 1973 to 72% in 1997. Globally, low-value food fish increased from 41% to 47% of food fish consumed for the same time period (33). However, it was noted that the rise in consumption was due, in part, to the poor in Asia (especially in China) increasing their consumption of farmed freshwater fish (33).

There are a number of reasons for this, beyond prices and supplies, which account for the spatial differences and fluctuations in human consumption of small pelagic food fish. They are:

- Increasing wealth in some countries, resulting in a switch to higher-valued fish, such as cods and haddock, and large pelagics, such as tuna and billfish;
- Substitution of small pelagic fish when there is limited availability of demersal and large pelagic fish;
- Increasing competition for small pelagic fish for fishmeal and for human consumption, driving the price of these pelagic fish up and making it difficult for poorer countries to purchase the fish; and
- Soybean price fluctuations, owing to the use of soymeal as a substitute for fishmeal in some industries.

Soymeal can be used as a substitute for fishmeal in intensive animal production, especially in the pig and poultry sectors. Soymeal can also substitute for fishmeal in aquaculture, although the fish cultured do not achieve the same high growth rates (34), and thus, it is the total supply and demand for protein meals that determine its price (35). If the total demand for protein meals increases, the price for protein meals will increase, including the price of fishmeal. This will also increase the likelihood that small pelagic fish, destined for human consumption, will be diverted to the reduction sector.

The trade that occurs in fishmeal and fish oil gives merit to the recent warnings of toxins in farmed salmon (36). The reduction process concentrates toxins, such as dioxins in fishmeal and oil. In northern Europe, where there are a high concentration of dioxins and large catches of forage fish, fishmeal and oil are likely to have high levels of dioxins. When these processed products are exported to other areas, dioxins and other toxins are also transported and enter the intensive animal food production system and ultimately the human food system. Recent concerns over fishmeal and fish oil toxicity have resulted in many companies developing the technology to filter out toxins such as dioxins (37).

FORAGE FISHERIES AND INTENSIVE FOOD PRODUCTION

Although fishmeal and fish oil are beneficial in the intensive production of poultry, pigs, and ruminants, they are essential to most farmed fish. Thus, the growth of aquaculture has led to a decline in the use of fishmeal in poultry and livestock. The demand for fishmeal in animal feeds is determined by the least cost of meals, especially soy, with the upper limit set by the taste imparted into the meat (38). Although soymeal can be substituted for fishmeal, the essential fatty acids in fishmeal and fish oil are superior to other meals, with several benefits such as increased disease resistance. Changes in consumption of fishmeal have led to increasing prices, which have had limited impact on livestock production because substitutes such as corn have been affordable. However, the increased demand for biofuels has changed the pricing structure of many inputs into animal feeds, and how this will change demand for fishmeal is uncertain.

Estimates of fishmeal consumption by the aquaculture sector on a national basis are lacking. The amount of fishmeal (as feed) consumed in the aquaculture sector was therefore estimated for countries with major fishmeal supplies (see Referenc 39 for details). China, India, Indonesia, the Philippines, Thailand, and Vietnam have large supplies of fishmeal. They also use fisheries bycatch as direct feed in aquaculture, which is often not recorded in official production statistics. This makes it difficult to reliably estimate the use of fishmeal in the aquaculture sector for these countries (40). Nevertheless, China's increasing fish and meat consumption makes it a major fishmeal consumer for farmed fish and pork production, and this contributes to rising fishmeal prices. China currently consumes more than 1.3 million tonnes of fishmeal each year and is investing in fishmeal companies in Peru and Chile to secure supplies.

In 2002, fishmeal and fish oil were primarily used throughout the world for intensive food production, with 24% for pigs, 22% for poultry, and 46% for aquaculture (40a). The farming of carnivorous species as well as changes in feeding practices for omnivorous fish species, such as shrimp and tilapia, have shifted fishmeal use patterns. Since 1981, the proportion of fishmeal used in aquaculture has been increasing, especially for high-value species (**Figure 9**).

The use of fishmeal by the aquaculture sector in 2002 was estimated to be 46%, with projections to 2012 of 60% (6) and with significant declines in the use of fishmeal in the poultry sector by 2012. In 2002, 81% of fish oil production was used in aquaculture, with projections of 88% in use by 2012 (6).

The aquaculture sector has increased its use of fishmeal in feeds since the early 1990s, but there is still considerable scope for the sector to increase its use of fishmeal. Currently, only half of global production is used in aquaculture, with the other half primarily used by the pig and poultry sector. How much more fishmeal can be diverted from pig and poultry consumption will depend, in part, on the price of fishmeal and soy meal. It also depends on the price increase consumers will pay for poultry and pigs. Clearly, as fishmeal demand increases in the aquaculture sector, fishmeal prices will increase, forcing pig and poultry producers to consider the trade-off between the unit cost of production and the increased risk of disease and lower meat quality if they substitute soymeal for fishmeal.

There is a trade-off in replacing fishmeal and oil with plant-derived products; studies have shown that, for young poultry and piglets, using fishmeal and fish oil in the diet increases disease resistance, decreases the impact of the disease if contracted, decreases the severity of inflammatory diseases, and improves the nutritional status of animals, leading to better quality and leaner meat. This reduces the overall unit cost of production compared to diets of exclusively plant-based meals (41).

The situation for fish oil, however, is different, with 87% of global fish oil production consumed by the aquaculture sector in 2003 (42). This is in spite of the industry developing feeds and improving feed conversion efficiency to reduce the amount of oil required, as well as searching for alternatives. A study (42) indicated that, by 2010, feed conversion efficiency should decrease, so that the use of fish oil in feeds should be reduced by 8% for salmon, implying that the scope for expansion will increase. However, considering how fast aquaculture has expanded in the past decades, a saving of 8% when the industry is already consuming over 87% will not be sufficient to allow for much more industry expansion of salmon and other carnivorous species.

Asia is the exception in this because fisheries bycatch is often fed directly to high-valued species, e.g., in China (43), Japan (44), Thailand, and Vietnam (40). The benefits of decreasing the amount of bycatch disposed of at sea are debatable. Some argue that it is better to use the fish than to return them to the ecosystem, whereas others argue that the biomass returned to the sea is beneficial in that it is recycled by other organisms (45). In some countries, fish bycatch is also a cheap source of food, e.g., Ghana, and therefore diverting bycatch can threaten local food security (46). There has been a trend in some countries to feed omnivorous and herbivorous fish aquafeeds containing fishmeal and fish oil to promote faster growth for a better return on investment, as seen in China (47). This is only possible if fishmeal and fish oil prices are low.

The expansion of aquaculture will continue to influence the production, trade, and consumption trends. How these trends will change depends on a number of international factors, including the international price of soymeal and fuel, as well as food quality and safety standards, all of which are currently in a state of flux.

POLICY OPTIONS AND FUTURES

Concern over forage fish sustainability, including the impacts of fishing on marine ecosystems, is increasing. The International Fishmeal and Fish Oil Organization explored the feasibility

of Marine Stewardship Council (MSC) certification but opted to develop their own Code of Responsible Practice. The intention of the code is to reassure users that the products are responsibly and carefully produced, and this code does not compete with ecolabels.

The industry will face significant challenges in meeting MSC certification because information on the effects of fishing is limited for most fisheries. This is seen in the UN Food and Agriculture Organization's (FAO's) State of Fisheries and Aquaculture reports, where reporting of fisheries on large geographic scales masks the status of small and locally important stocks. Managers and policy makers should take a precautionary approach that includes ecosystem-based management for forage fish fisheries because of the influence of oceanographic conditions and the unknown consequences of climate change and associated warming sea temperatures.

In a future of expanding aquaculture without fishmeal and oil alternatives, the price of fishmeal and fish oil will likely rise, and the meals and oils will be increasingly consumed in the aquaculture sector at the expense of first the poultry sector and second the pig sector. Increasing prices will ultimately increase production costs, with consumers paying more for farmed fish, and will affect the food security of developing countries by pricing forage fish and farmed fish out of their price range.

A world of expanding aquaculture and price-competitive alternatives to fishmeal and fish oil will likely result in the forage fish fisheries continuing at current levels, but the price of fishmeal and fish oil decreasing as demand is lowered. However, if fuel costs continue to rise, some fleets may decrease, so that only the most economically efficient vessels operate. In such a scenario, it is possible that other uses of fishmeal and fish oil in higher-value products, such as human food and pet food, will be expanded.

Similar to an expanding aquaculture sector if production of soymeal slows or stalls, the price of fishmeal and fish oil will rise with declining supplies. Pressure to find new sources of fishmeal as well as initiatives to improve the food conversion ratios will increase. Such a scenario has significant implications for food security because high prices could see low-value fish destined to developing countries diverted to reduction plants instead. This scenario also has implications for the use of bycatch, with an even greater incentive to use it in the aquaculture sector either as direct feed or as inputs to fishmeal and fish oil.

SUMMARY POINTS

1. The composition of landings of forage fish fisheries have changed over the past 50 years with the trophic level of fish used in fishmeal increasing over the past 20 years.
2. Our understanding of the role of forage fish in marine ecosystem and the impact of fishing is still limited.
3. Landing of forage fish peaked by the 1970s, and these high levels are highly unlikely in the future, even if fisheries are managed sustainably.
4. The consumption of forage fish by seabirds and marine mammals is not likely to be onerous to fisheries, except in a few localized areas. By contrast, fisheries, by reducing the biomass of small pelagics, might pose a threat to these predators, particularly to those species for which stocks have been heavily depleted by human exploitation in the past.
5. Some forage fish species are consumed by many people with consumption patterns changing over the last 20 years.
6. Aquaculture continues to increase its consumption of fishmeal and fish oil.

FUTURE ISSUES

1. The demand for fishmeal and fish oil may not be met, constraining the expansion of aquaculture until alternative feeds are found.
2. Our lack of understanding of how forage fish will respond to climate change will limit industry's ability to plan or adapt to these changes.
3. Certifying forage fisheries to MSC standards (or similar) will be difficult because information on the impacts of these fisheries on marine ecosystems is poor.

DISCLOSURE STATEMENT

The authors are not aware of any biases that might be perceived as affecting the objectivity of this review.

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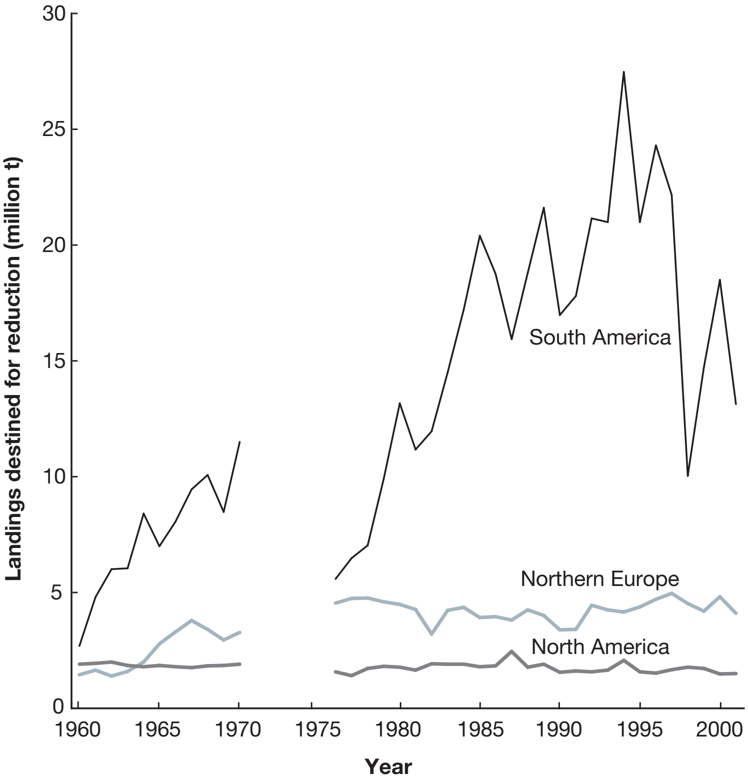
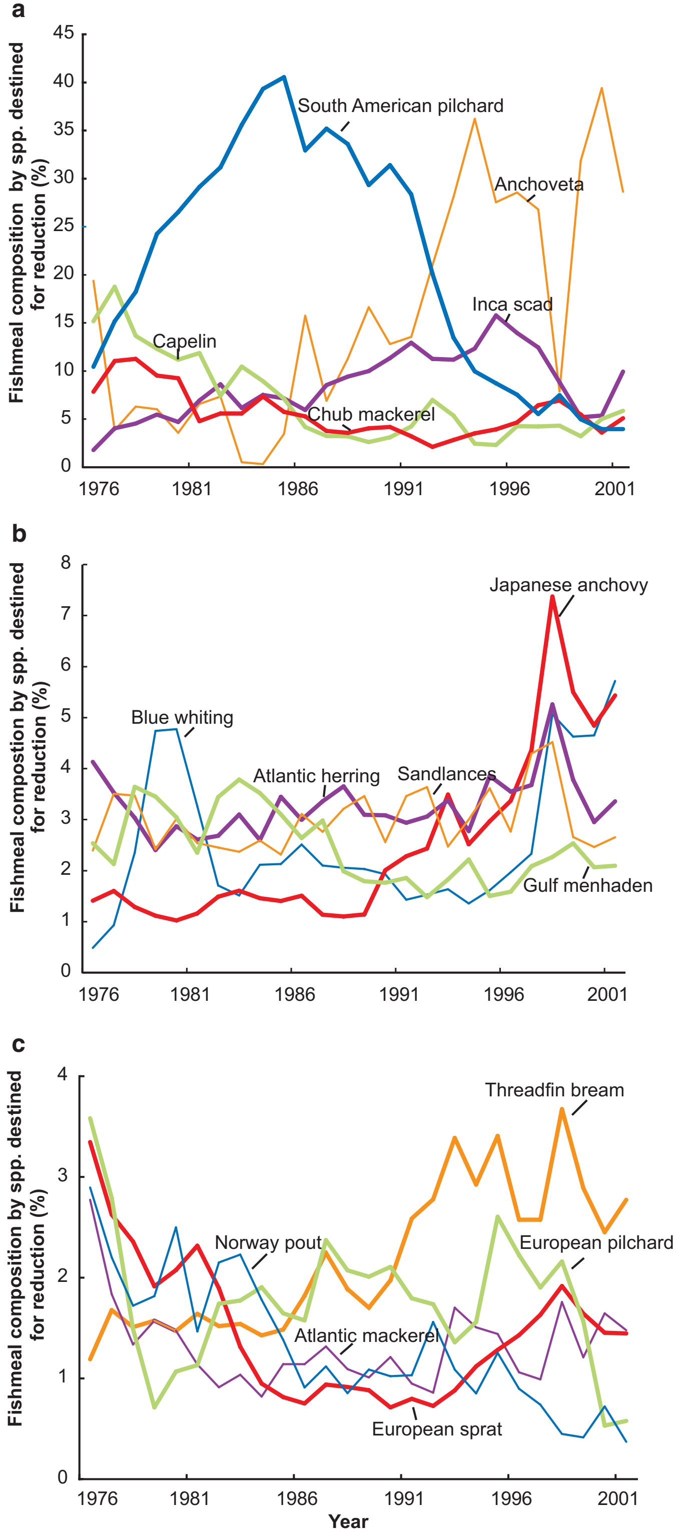


Figure 1

Trends in landings for reduction fisheries 1960 to 2001, by major regions. Region-specific information is not available between 1970 and 1976 (48, 49).


a
Fishmeal composition by spp. destined for reduction (%)
South American pilchard
Anchoveta
Inca scad
Capelin
Chub mackerel
b
Fishmeal compostion by spp. destined for reduction (%)
Japanese anchovy
Blue whiting
Atlantic herring
Sandlances
Gulf menhaden
c
Fishmeal composition by spp. destined for reduction (%)
Threadfin bream
Norway pout
European pilchard
Atlantic mackerel
European sprat
Year

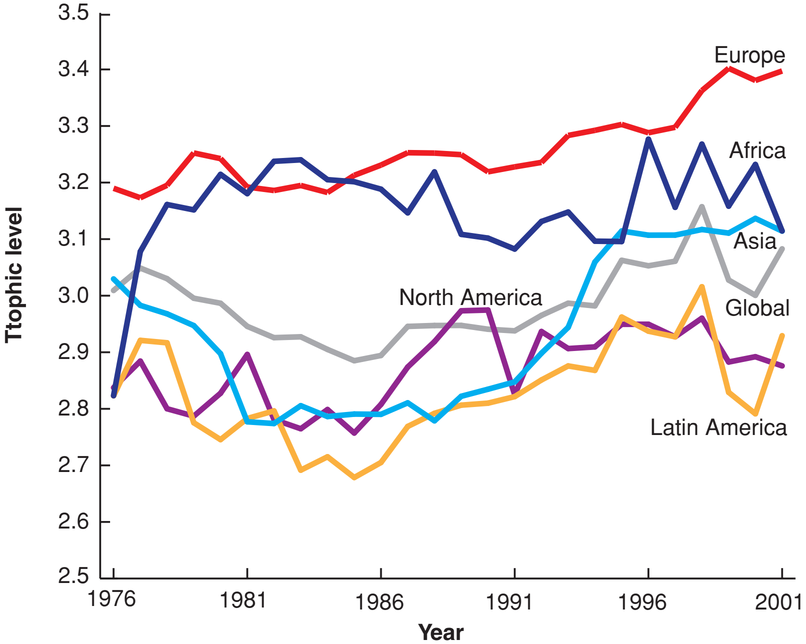


Figure 3

Trend in weighted mean trophic level of fish destined for reduction from 1976 to 2001 (49). The mean trophic level was calculated as described in Pauly & Watson (17).

Figure 2

Trends in the composition of fishmeal on the basis of the top species destined for reduction that made up at least 75% of the fish used by volume for reduction in 1976 and 2001; (*a*) top five species by volume, (*b*) middle five species by volume, and (*c*) bottom five species by volume (49).

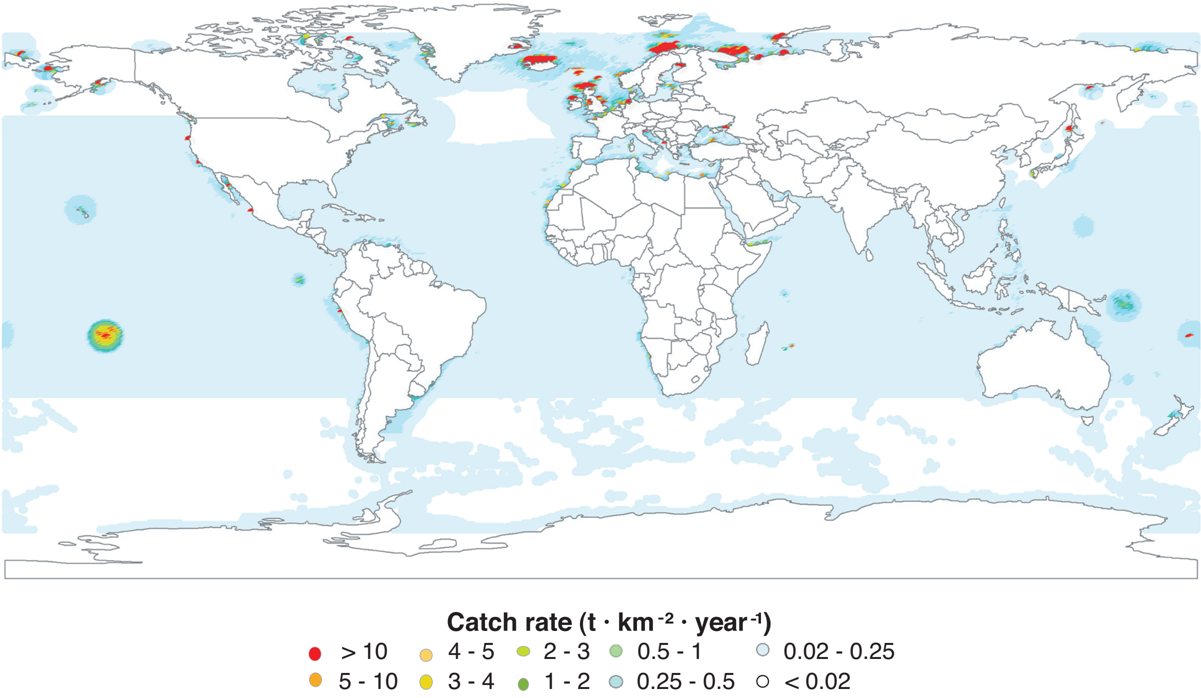


Figure 4

Map of predicted global small pelagic fish consumption rate by all seabirds combined for an average year in the 1990s.

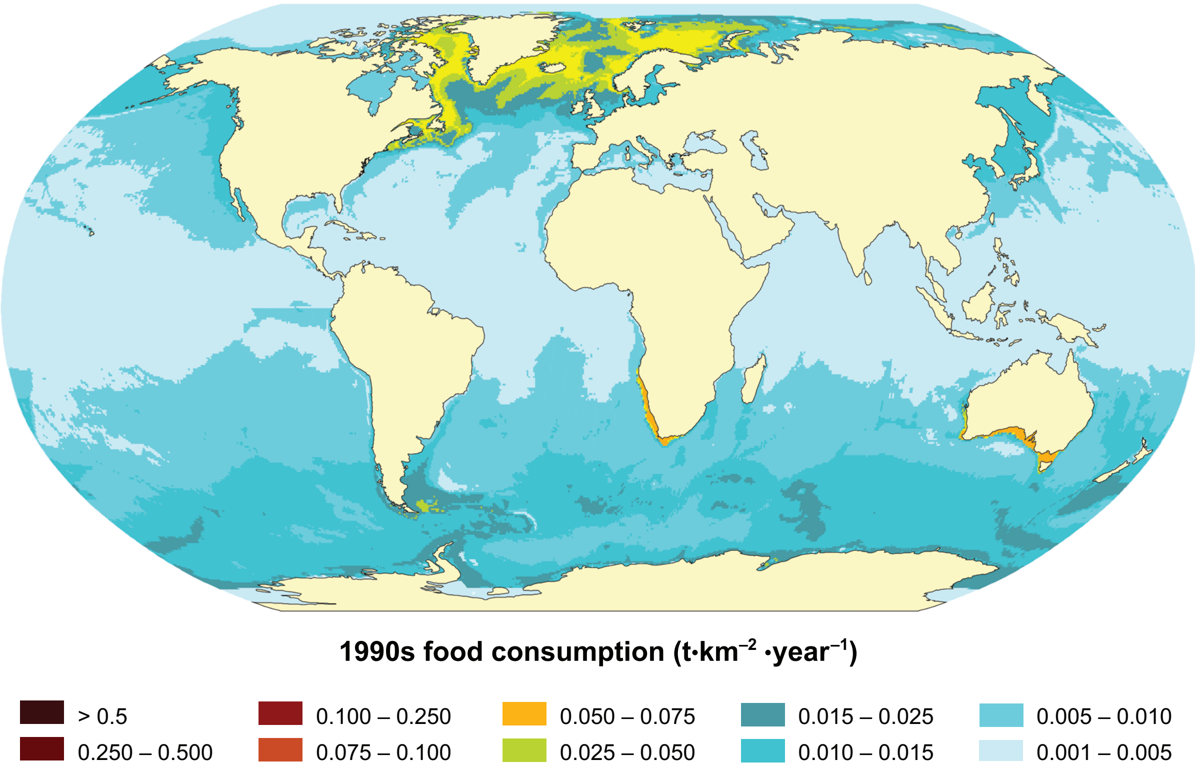


Figure 5

Distribution of estimated marine mammal food consumption rates (t·km^{-2}·year^{-1}) of small pelagics for an average year in the 1990s (22).

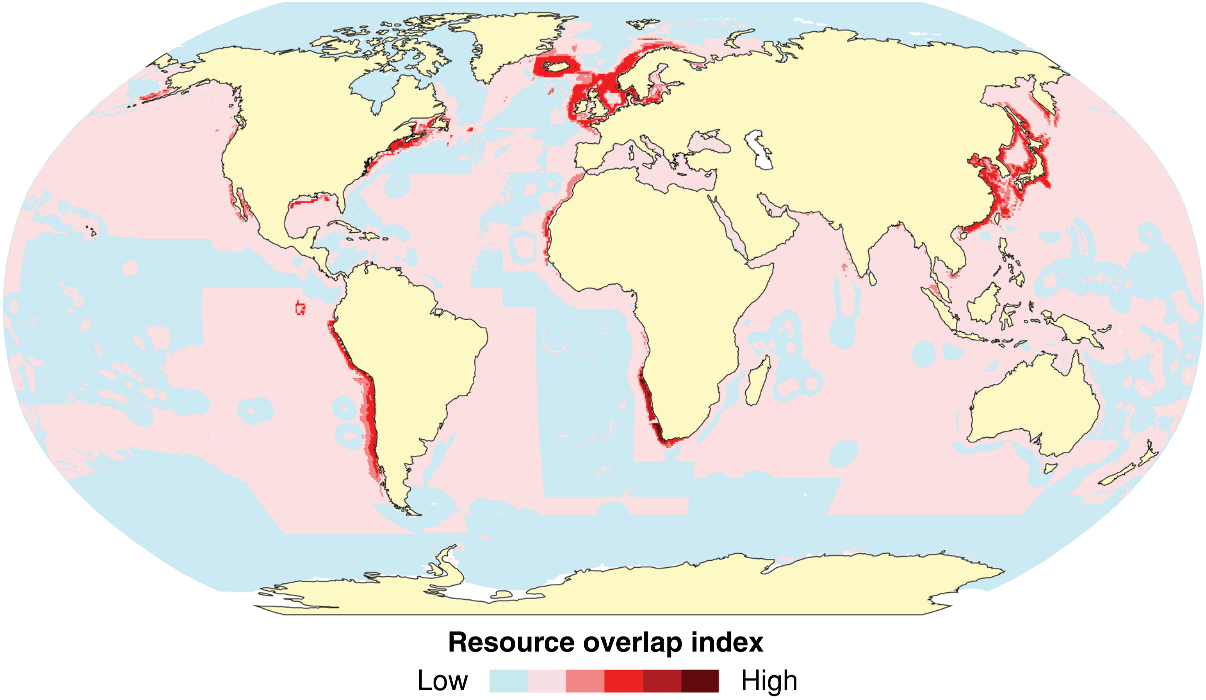


Figure 6

Map of estimated overlap in resource exploitation of small pelagics by marine mammals and fisheries for an average year in the 1990s.

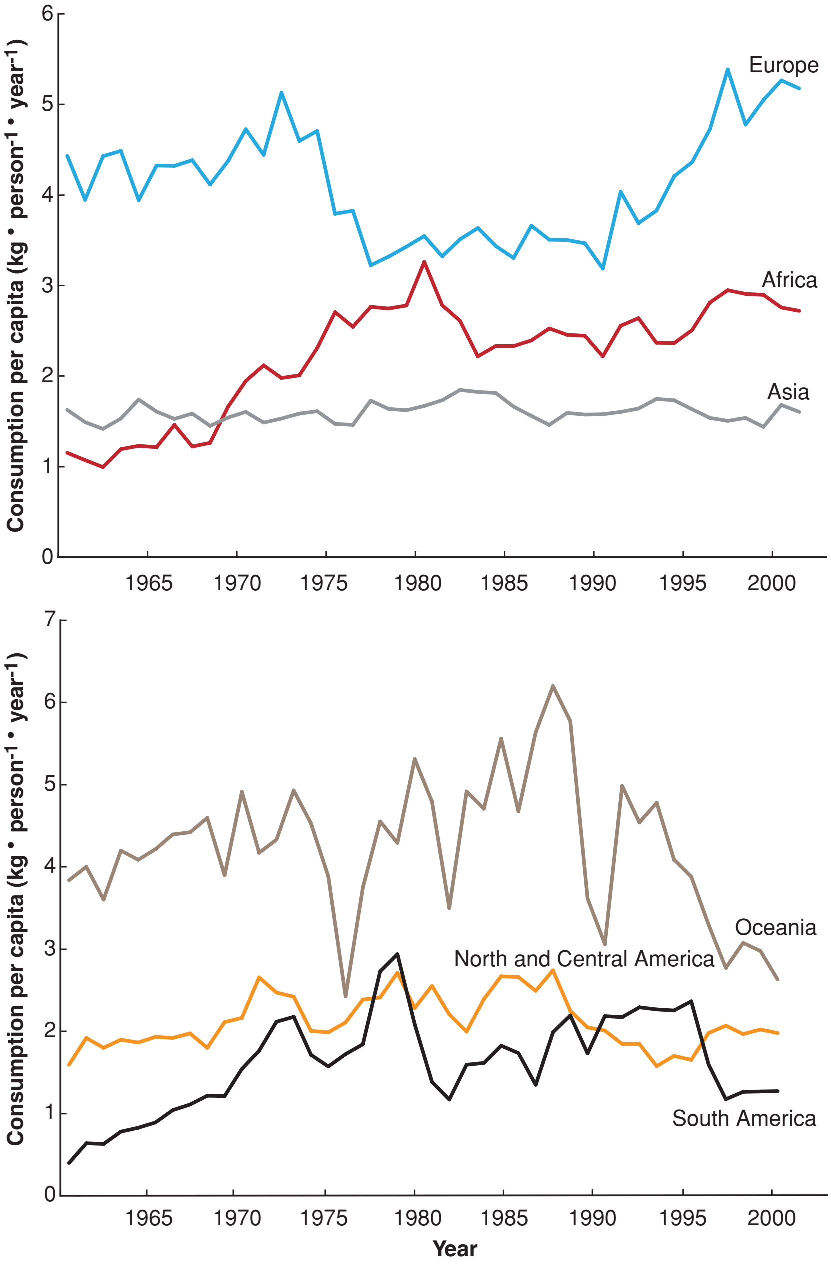


Figure 8

Per capita consumption of small fish from 1961 to 2002 (51).

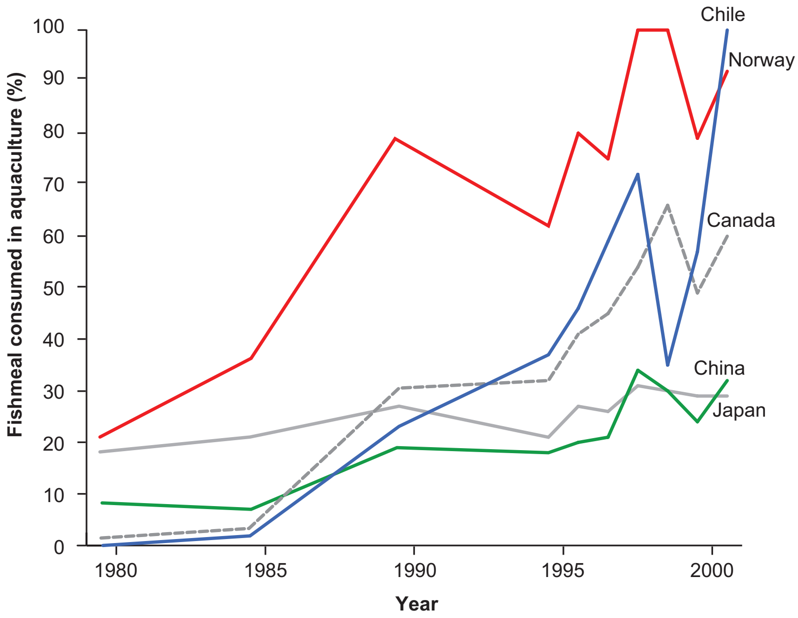


Figure 9

Proportion of fishmeal consumed in aquaculture for major aquaculture-producing countries in 1980, 1985, 1990, 1995, and 2001 (52–55).

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